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A STUDY OF THE ELASTIC PROPERTIES OF ORIENTED FIBERGLASS BY THE IMPULSE ACOUSTICAL METHOD

by

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EDITED MACHINE TRANSLATION

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH

DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

A STUDY OF THE ELASTIC PROPERTIES OF ORIENTED FIBERGLASS BY THE IMPULSE ACOUSTICAL METHOD

Ye. N. Kvasnikov, and A. I. Potapov

Some of the essential mechanical characteristics of fiberglass are the elastic modulus and Poisson's ratio. For determining the elastic characteristics of oriented fiberglass, we used the impulse acoustical method, since it permits revealing the influence of different technological factors and the mode of hardening for mechanical properties of the material.

<u>Elastic properties of oriented fiberglass</u>. Oriented fiberglass belongs to the group of orthogonally-anisotropic materials. Elastic deformations of fiberglass can be described with the aid of Hooke's generalized law. In general, the equations of Hooke's generalized law contain 21 elastic constants. However, inasmuch as constructions made of fiberglass such as pipes, plates, the hulls of ships, constructions used in wall and roof panels and others are subject to plane stress and have an orthotropic structure, then the equations of Hooke's generalized law will have four independent elastic constants in all.

With the aid of the impulse acoustical method, the physical constants of Hooke's generalized law are directly determined [1]:

$$c_{11} = v_x^2\rho, \tag{1}$$
$$c_{22} = v_y^2\rho, \tag{2}$$
$$c_{66} = v_{xy}^2\rho = v_{yx}^2\rho. \tag{3}$$

where ρ – density; v_x and v_y – speed of propagation of longitudinal waves in a plate along the axes of elastic symmetry x and y; v_{xy} and v_{yx} – corresponding propagation speeds of shear waves.

By using formulas (1-3) and the expression of technical elastic constants through the physical [2, 3], the values of Young's modulus E and shear modulus can be obtained:

$$E_x = v_x^2\rho\,(v_x^2/v_y^2 - \mu_{21}^2), \tag{4}$$

$$E_y = v_y^2\rho\,(v_y^2/v_x^2 - \mu_{12}^2), \tag{5}$$

$$G_{xy} = v_{xy}^2\rho, \tag{6}$$

where μ_{12} and μ_{21} – Poisson's ratio, subscripts x and y, as before, pertain to the direction of the axes of elastic symmetry, while C_{11}, C_{22}, C_{66} – physical elastic constants.

For determining the elastic characteristics in rods it is possible to use this expression:

$$v_\varphi = \sqrt{\frac{E_\varphi}{\rho}}, \tag{7}$$

where v_φ – speed of elastic waves in the rod; E_φ – Young's modulus, and subscript φ indicates direction. This formula is accurate for directions, which coincide with the axes of elastic symmetry. In the first approximation dependence (7) can also be accepted for other directions.

By equating the values of elastic modulus obtained by the speed of propagation of waves in a plate (4) and (5), to the corresponding values calculated by the speed of propagation of waves in a rod (7), one can determine μ_{12} and μ_{21}:

$$\mu_{xy} = \sqrt{\frac{v_x^2 - v_0^2}{v_y^2}}, \quad (8)$$

$$\mu_{yx} = \sqrt{\frac{v_y^2 - v_{90}^2}{v_x^2}}, \quad (9)$$

where v_0 and v_{90} – speeds of longitudinal waves in a rod along axes x and y.

For determination of E_ϕ there is no need to cut rods in directions which differ from the basic, and it is possible to use the known formulas of the theory of elasticity of an anisotropic body [2, 3]. By applying the previously deduced expressions (7) and (8), we will obtain:

$$E_\varphi = \frac{v_y^2 \rho (v_x^2/v_y^2 - \mu_{yx}^2)}{\cos^4\varphi + b \sin^2 2\varphi + \lambda \sin^4\varphi}, \quad (10)$$

where

$$\lambda = \frac{v_x^2}{v_y^2}, \quad b = \frac{v_y^2 (v_x^2/v_y^2 - \mu_{yx}^2)}{v_{45}^2} - \frac{\lambda + 1}{4},$$

here v_{45} – speed of longitudinal waves in a rod, cut at an angle of 45° to the direction of the fibers.

Below, on the basis of experimental data, it will be shown that for determining the speed at any angle to the direction of fibers both in a plate and in a rod this formula is applicable:

$$v_\varphi = \frac{v_0}{\cos^4\varphi + b_1 \sin^2 2\varphi + \lambda \sin^4\varphi}, \quad (11)$$

where

$$\lambda = v_0/v_{90}, \quad b_1 = v_0/v_{45} - (\lambda + 1)/4,$$

here v_0, v_{45}, v_{90} – speed of propagation of elastic waves either in a rod or in a plate at angles of 0°, 45° and 90° to the direction of the fibers.

Formula (11) is empirical and was taken by analogy with the theoretical equation.

Experimental investigations. As the object of investigation the anisotropic fiberglass material SVAM was selected, the physical and mechanical properties of which have been sufficiently completely and widely discussed in literature [4]. For investigating the elastic characteristics by the impulse acoustical method [5, 6] SVAM material made by the Leningrad laminated plastics plant was used. The characteristics of these materials are given in Table 1.

Table 1. Characteristics of sheet fiberglass SVAM adhesive – epoxy-phenol resin.

Sheet number	Dimension, mm	Density, g/cm³	Content of fiberglass, weight %	Ratio of longitudinal and transverse fibers
3-1	500×500×4.9	2.08	78	1:1
3-1**	500×500×5.3	2.01	72	1:1
3-5	500×500×5.0	2.07	77	1:5

All fiberglass of the sheets were marked and sonicated in accordance with the layout shown in Fig. 1. As an emitter of ultra-acoustic waves the Polish ultrasonic instrument Betonoskop was used, as well as elastic wave converters on a frequency of 40 kHz. As a result of sonification the speed of propagation of elastic waves in a plate of fiberglass in the directions shown in Fig. 1 was determined; after that, from each sheet at angles of 0°, 15°, 30°, 45°, 60°, 75° and 90° to the direction of fibers from 4 to 5 samples each were cut. The length of the samples was from 200 to 400 mm, the width was 20 mm, and the thickness corresponded to the thickness of sheets shown in Table 1. All of the samples were sonified to determine the speed of elastic waves in the rods by the layout shown in Fig. 2. The values of speeds in the plate and in the rods were compared with the values of speeds calculated by formula (11).

Along with measurements of elastic properties, mechanical tests were conducted of material by the acoustical method for determining the value of elastic constants in accordance with All-Union State

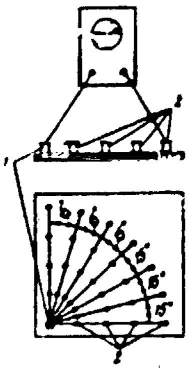

Fig. 1. Location diagram of the emitter (1) and the receivers (2) during surface sonification of a plate made of fiberglass.

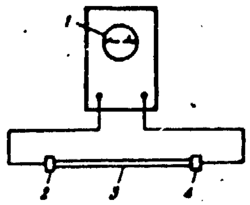

Fig. 2. Diagram of through sonification of fiberglass samples. 1 – ultrasonic instrument. 2 – emitter. 3 – sample. 4 – receiver.

Standard 9550-60. The very same samples were subjected to the mechanical tests on which the dynamic elastic characteristics were determined by the acoustical method.

As a result of the tests Young's moduli were determined in directions of 0°, 15°, 30°, 45°, 60°, 75° and 90° to the direction of fibers in the fiberglass.[1] All measured and calculated data are given in Table 2.

These data show that the dynamic elastic characteristics noticeably differ from the static, where this difference is increased with a change of angle between the direction of sonification and the axis of elastic symmetry, reaching a maximum value for the direction with minimum elastic modulus. The dependence of the elastic modulus on the

[1]Let us note that for the first two sheets, the axes of symmetry coincided with the directions 0°, 90° and 45°, and for the last one only with two – 0° and 90°.

Table 2. Results of determining the elastic characteristics of SVAM oriented fiberglass by the impulse acoustical method.

Direction of fibers	Speed of propagation of longitudinal waves, m/s: in a plate, experimental values	in a plate, theoretical values (11)	in a rod, experimental values	in a rod, theoretical values (11)	Dynamic elastic modulus, kgs/mm²: experimental values	theoretical values (11)	Static elastic modulus, kgs/mm²: experimental values	theoretical values [2, 3]	Conversion factor to: experimental values	theoretical values
Sheet L-1										
0	4430	4430	4350	4350	3030	3030	3120	3120	0,79	0,79
15	[illegible]	4290	4200	4180	3690	3040	2780	2520	0,76	0.72
30	4030	4010	3930	3880	3210	3140	1870	1840	0,58	0,60
45	3900	3800	3750	3750	2910	2910	1640	1640	0,56	0,56
60	4030	4010	3900	3880	3180	3140	1840	1850	0,58	0,60
75	4270	4250	4190	4180	3650	3610	2650	2530	0,73	0,72
90	4430	4430	4350	4350	3030	3030	3120	3120	0,79	0.79
Sheet L-1**										
0	4430	4430	4400	4400	3800	3800	3250	3250	0,84	0,84
15	4320	4280	4230	4220	3600	3580	3100	2880	0,86	0,79
30	4000	4020	3900	3010	3150	3060	1940	1980	0,62	0,67
45	3900	3890	3740	3740	2310	2810	1730	1720	0,62	0,62
60	3960	3960	3850	3830	2200	2960	2090	1900	0,70	0,65
75	4130	4170	4020	4080	3250	3310	2310	2226	0,71	0,74
90	4240	4290	4210	4210	3560	3560	2820	2820	0,79	0,79
Sheet L-5										
0	4860	4860	4790	4700	4730	4730	4180	4180	0,88	0,88
15	4650	4630	4580	4500	4330	4320	3120	3150	0,72	0,73
30	4190	4190	4070	4070	3430	3430	2310	2000	0,68	0,64
45	3840	3840	3730	3730	2880	2880	1650	1650	0,57	0,57
60	3740	3720	3630	3620	2770	2720	1700	1680	0,62	0,60
75	3750	3740	3650	3600	2780	2780	2050	1980	0,74	0,70
90	3700	3780	3710	3710	2850	2860	2180	2160	0,76	0,76

Note. Values of constants were calculated by formulas (4), (5), (7), (8), (10) and (12) in this article.

rate of application contradicts its physical sense. This dependence is explained by the fact that in fiberglass, along with elastic deformations, highly elastic deformations are also developed. When testing by the impulse method, samples of fiberglass experience minute stresses at extraordinarily high rates of load application; therefore, the fiberglass does not "succeed" in manifesting nonelastic properties.

For converting from the elastic characteristics determined by the acoustical method to the characteristics obtained in the standard tests, it is possible to use conversion factors. Determination of these factors was made by comparing the dynamic elastic characteristics with the elastic characteristics defined by the All-Union State Standard. The results of this comparison are given in Table 2, where the conversion factors were obtained in the following way:

$$K_{\text{эксп}} = E^{\text{дин}}_{\text{эксп}}/E^{\text{стат}}_{\text{эксп}}, \quad K_{\text{расч}} = \frac{K_0}{\cos^4\varphi + \beta\sin^2 2\varphi + \lambda_2\sin^4\varphi}, \tag{12}$$

where

$$\lambda_2 = \bar{K}_0/\bar{K}_{90}, \quad \beta = K_0/K_{45} - (\lambda_2 + 1)/4.$$

In conclusion, it is possible to note that the impulse acoustical method permits reliably determining the elastic characteristics of fiberglass.

The investigations conducted showed that acoustical parameters and dynamic elastic constants of orthotropic fiberglass are described with sufficient accuracy by tensor formulas of the theory of elasticity of an anisotropic body. For converting from dynamic elastic characteristics to standard, conversion factors were obtained which consider the pressure of nonelastic deformations in a polymeric adhesive.

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ABSTRACT

(U) The impulse acoustical method was used to determine the elastic properties of SVAM oriented glass reinforced plastics. Formulas were given for Young's modulus, shear modulus, and Poisson's ratio. These constants were related to the density of the material and the speed of elastic wave propagation in the material. An equation was given for the speed of elastic wave propagation in any direction as a function of the angle and speed of propagation relative to the fiber direction. Experimental values of the elastic constants were obtained in three SVAM materials having an epoxy phenol resin binder, densities ranging from 2.01 to 2.08 g/cm (superscript 3), glass fiber contents ranging from 72 to 78 wt percent, and ratios of longitudinal to transverse fibers of 1 to 1 ratio and 1 to 5 ratio. A schematic diagram showed the experimental arrangement of ultrasonic generator, receiver, and sample. The speed of elastic wave propagation was measured in samples at angles of 0, 15, 30, 45, 60, 75, and 90 degrees to the fiber direction. ~~Samples were 200 to 400 mm long, 20 mm wide, and 4.9 to 5.3 mm thick.~~ Mechanical testing was done to determine values of the elastic constants for comparison with the impulse acoustical method. Experimental results were given for the modulus of elasticity as determined by static and dynamic methods.

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